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Water Capacity of Paramo Soils

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A comparative study of soils in native paramo landscape and alpaca pastures

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Abstract

The pàramo ecosystems in the high Ecuadorian Andes are grasslands characterized by challenging abiotic factors such as low temperatures and high solar radiation. Another key feature of pàramos is the humidity and water availability in the ecosystem. Pàramos are very important to the hydrology of the inter-Andean valley because they are water reserves that distribute fresh water to lower elevations. These hydrologic properties are made possible by the porous volcanic ash soils formed by the volcanic arc along the mountain range. This study is focused in the region of Chimborazo approximately 20 km from Riobamba the capitol city of the province in a community Pulingi-San Pablo. This community is an indigenous community working with the Reserve of Chimborazo and other organizations such as SocioPàramo to protect the ecosystem as well as develop sustainable and effective sources of income for the community. This study observes the impacts of the alpaca pastures on the plant communities and soils in the ecosystem. By taking undisturbed soil samples, properties such as bulk density, water content, porosity, and percent of saturation are measured and compared to the vascular plant growth forms coverages of plots in an alpaca pasture and a site not impacted by grazing. The transect in the alpaca pasture had a high overall percent coverage of plant growth forms while the percent coverage along the other transect was significantly lower. The first transect also had a lower bulk density than the soils in the second transect unaffected by pastures. The water content, porosity, and degree of saturation were much higher in the alpaca pasture than in the unused pàramo. The alpacas appear to have little to no impact on the plant communities and soils on Transect 1 because overgrazing causes lower percent coverage of plants, high bulk density in soil, and lower water content and porosity. The results of this survey do not indicate any of these factors. Other studies (Ramsay, 1997; Vasconez, 2011; Poulenard, 2001) indicate that the trends noted in this investigation are more likely from abiotic factors such as the temperature change on an altitudinal gradient. At higher altitudes, the colder temperatures cause less weathering, meaning the soils are sandier and less developed increasing the bulk density, and lower porosity of the soils. The lower temperatures also create a more challenging environment for plant development allowing for a more diverse composition of growth forms.

Resumen

Los páramos son ecosistemas en la Cordillera Andina. Estas praderas están caracterizadas por factores abióticas muy duraos, como temperaturas muy bajas y altos niveles de radiación solar. Otro aspecto clave de los páramos es la humedad y cantidad de agua dulce en este ecosistema. Los páramos son muy importantes en la hidrología del valle inter-andino porque son reservas de agua que distribuyen está a las áreas más baja. Las propiedades hidrológicas son propias de las comunidades de los suelos porosos y volcánicos que forman el arco volcánico que sigue la cordillera de montañas. Este estudio está localizado en la región de Chimborazo aproximadamente a 20 km de la ciudad de Riobamba, en la comunidad de Pulingi-San Pablo. Es una comunidad indígena que está trabajando con La Reserva de Chimborazo y otras organizaciones como Socio Páramo, par a proteger el ecosistema y desarrollar fuentes de ingresos sostenibles y efectivos para la comunidad. Esta investigación observa los impactos del pastoreo de las alpacas en las comunidades de plantas y los suelos del ecosistema. Se tomó muestras sin alteración para

medir las propiedades de densidad aparente, contenido de agua, porosidad, y saturación, así como comparar las comunidades de plantas de dos sitios, una expuesta al pastoreo y el otro de cobertura vegetal de páramo sin alteración. El transecto en el pasto de las alpacas tiene una cobertura muy alta de formas de crecimiento de plantas, y la cobertura a lado del otro transecto fue más baja. También, el primer transecto tiene una densidad aparente más baja, en comparación del segundo que no tiene efectos del pastoreo de alpacas. El contenido de agua, porosidad, y saturación fueron más altos en los pastos del páramo nativo. Al parecer las alpacas no causan un impacto en las comunidades de plantas y los suelos en el Transecto 1, porque el sobre pastoreo causa un bajo porcentaje de cobertura de plantas, contenido de agua y porosidad, y una densidad aparente más alta. Los resultados de este estudio no indican ninguno de estos factores. Otras investigaciones (Ramsay, 1997; Vasconez, 2011; Poulenard, 2001), muestran tendencias que se observaron en esta investigación en cuanto a factores abióticos como el cambio de temperatura en el gradiente altitudinal. A altitudes más altas, la temperatura es más fría y causa menos desgaste, por eso los suelos contienen más arena y hay menos desarrollo. Esto causa un incremento y densidad aparente, y una inferior porosidad. Las temperaturas bajas también crean un ambiente más difícil para el desarrollo de plantas que permite unas comunidades más diversas de composición de formas de crecimiento.

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I would like to thank the School for International Training (SIT) and their staff for the opportunity to conduct this investigation. Specifically, the program directors of the Ecuador: Comparative Ecology and Conservation program Xavier Silva, Javier Robayo, and Diana Serrano for their advice and guidance throughout each stage of this project as well as the materials resources they provided for me to use throughout the project. I would also like to thank the Community and Staff at Casa Condor for their hospitality and willingness to have me as their guest while I conducted this project. A special thanks to my advisors, Olmedo Cayambe and Ana Maria Ortega who have given very valuable advice and critiques throughout the research process.

Background

The paramo is an ecosystem located in high mountain tropical regions. In South America, the paramo extends along the Andes from Venezuela to Peru. In Ecuador, the Paramos cover 12,650km2 which is approximately 5% of the country (Mena Vasconez, 2011). There are also paramos above the tree line and below the glaciers between 4000m and 5200m (Mena Vasconez, 2011).

Paramos are characterized by a cold and humid climate with high variation in daily weather patterns. Although there are no different seasons throughout the year in the paramo, the average daily temperatures in paramos range from 0 C to 12 C while at night the temperature is usually below 0 and up to 25 C at midday (INAMHI, 2018). These diurnal seasonal conditions prove to be very rigorous and challenging for the survival of plants and animals in the region. Despite these conditions roughly 10% of Ecuador’s flora species are found in these ecosystems (Vasconez).

Unlike temperature, humidity and precipitation are very variable and unpredictable daily and annually ranging from 700mm and 300m (Luteyn 1992). The amount of rainfall depends greatly on the location of the ecosystem in reference to the rain shadows and other climate patterns. Historically, paramo regions are very important water reservoirs because of the availability of fresh water and the regions unique ability to also redistribute water to lower more populated elevations. Because of the presence of the glaciers in the peaks, the constant humidity, and the small human populations with the ecosystem, these regions have been able to provide a source of fresh water for ecosystems as well as human populations at lower elevations. The high concentration of water and the limited impacts of pollution and degradation of the unique plant life and the volcanic soils that provide compose a hydrologic system fit for distributing fresh water to streams that flow into the basins.

Because of the large altitudinal range of the paramo, it can be divided into three subcategories: the subparamo, paramo, and superparamo. The subparamo is the lowest level in altitude of the paramo beginning depending on the local climate as low as 2800m. This zone is characterized by being an intermediate zone between the true paramo and the tree line. The paramo zone begins at an elevation around 4000m where there ceases to be trees and other larger plants. The superparamo is the highest part of the paramo beginning around 4400m (Mena Vasconez et al, 2011). This zone contains soils that are not nearly as developed as the other levels, so the flora present are not nearly as abundant and are mostly composed of mosses and lichens.

Paramo Flora Although there are many similarities in the flora present in the paramo plant communities, the composition of these communities varies greatly with location. Ramsay developed a Twinsplan classification system to demonstrate the diversity of paramos at a community level (Ramsay 1997). This system contains 12 Twinspan classes which are “Tussock Puna”, “Cushion Desert Paramo”, “Acaulescent Rosette and Cushion Paramo with Tussocks”, Upright Shrub Paramo, “Acaulescent Rosette Paramo”, “Acaulescent Rosette and Cushion Desert Paramo”, “Acaulescent Rosette and Prostrate Shrub Paramo”, “Stem Rosette and Erect Herb Paramo”, “Stem Rosette and Tussock Paramo”, “Basal Rosette Desert Paramo”, and two different classes of “Tussock Paramo”. These classes were named for the different growth form that are established in the paramos.

The growth forms and species present in the paramo are affected by three main factors: climate, human impact, and the soil type. In the paramo, plants are exposed to many harsh conditions that are associated with being at a high altitude in the tropics such as the low pressure, drastic diurnal temperature changes, high levels of ultraviolet radiation, and strong winds (Mena Vasconez, 2006 and Ramsay, 1992). Due to these unique and difficult conditions, many plants have developed similar adaptations to navigate these challenges. For example, many successful plants use the strong winds to disperse their seeds rather than producing fruits to attract animals. Many of these adaptations are considered convergent evolution because of the wide variety of genera and families present in the paramo ecosystem. According to taxonomical studies, the most successful plants in the paramo originated from temperate zones that had preexisting adaptations to survive in colder climates rather than tropical plants that were dispersed at higher altitudes (Cuello, 2010).

It is debated on whether altitude or humidity affects the diversity and composition of the flora communities in the paramo more. Many studies have been conducted on the vegetation on the altitudinal gradient of the paramo comparing the different zones present (subparamo, paramo, super paramo). Tussocks ad grasses dominate lower altitude zones in the paramo and lose this dominance and form more diverse communities with rosettes, cushions and shrubs at higher altitudes (Keating 1999 and Ramsay 1992). Studies such as an investigation by Cuello et al in a Venezuelan paramo, compared the impacts of elevation to that of humidity and precipitation on paramo plant communities and found that humidity is much more impactful on the composition and diversity of plant life in the paramo based on phytogeographical comparisons between dryer paramos and wetter paramos (Cuello et al, 2010).

Paramo Soils The foundation of all ecosystems is the soil and the paramo is no different. The paramo soils play an intricate role not only in the development of plant communities but also in the hydrologic cycle.

The formation of soils depends on parent material, climate, and time. The parent material depends on the regional geology and the rocks and minerals being weathered or deposited in the area. In the Ecuadorian Paramos, there is a divide in the parent material between the northern paramos and southern paramos. The soil in the northern paramos comes from volcanic parent rock. Volcanic ash tuffs and pumice are deposited along the mountains by eruptions of the stratovolcanoes along the cordillera in the "Quaternary northern volcanic zone" or Carnegie Zone (Buytaert, 2005). This zone of the ring of fire extends from Columbia to central Ecuador. The parent material of the southern paramos is a metamorphic formation that was uplifted into the Andes mountain range as a result to the upwelling in the subduction zone (Buytaert, 2005). Although soil material is very different, both soils play an important role in absorbing and dispersing water.

The climate also has a great effect on the type of soil because of its impact on physical and chemical weathering. Although the average temperature in the pȧramo is very low, the nightly freezes cause physical wedging such as freeze-thaw where the expansion of frozen water in rocks breaks down the material. Cold climates rarely exhibit high rates of chemical weathering because the low temperatures slow down chemical reactions requiring more time to develop. Since altitude affects the temperatures in the region, higher zones of the pȧramo, such as the superpȧramo have poorly developed soils.

Time affects the amount of weathering that can take place. In the southern pȧramos contain many clays which are the remains from chemical weathering, are much older soils than those northern påramos which are formed by very recent volcanic eruptions. The three main soil types found in the påramo are andisols, histisols and entisols. Andisols are soils that come from volcanic parent material such as most of the soils found in the northern påramos. Histisols are very moist soils that contain a high concentration of organic material and water. Entisols are very underdeveloped soils containing lots of rocks and sand that haven't fully been weathered into soils.

The påramo soils impact the plant growth in the ecologic communities. Andesite ashes are very nutrient rich because they contain minerals such as amphibole and pyroxene which easily breakdown and replenish nutrients in the soils (Vasconez, 2006). These soils are commonly described as dark black in color not only because of the black minerals that they are commonly composed, but also contain high concentrations of organic matter. The ashes are also deposited in a wind resistant and stable structure and maintain a high porosity which is very conducive to root development and hydraulic conductivity (Poulinard, 2001). The high porosity and the quantity of organic matter allow for very good drainage and absorption of water with minimal damages to the ecosystem.

Human land-use impacts these soil properties in many ways including compressing or loosening the soil (Poulinard, 2001). Compressing the soil increases the bulk density of the soil. Bulk density is a quantification of compaction (dry material by unit volume). Loosening the soil decreases the bulk density and destroys the stable structure and allows for more soil to be lost by wind and water erosion. Many areas in the lower påramo, have been converted to land dedicated to afforestation of exotic pines. These afforested zones change the stable chemistry of the soil redistributing and concentrating nutrients in different levels of the soil (Farley, 2003). Although the afforestation of pines is an effective method of carbon sequestration, other studies have shown that these pines have a strong impact on the regional hydrology, reducing the water regulation capacity of the soils in the ecosystem (Crespo et al, 2010; Harden et al, 2013). Overgrazing is a major issue with human land use in the påramo. This land use causes degradations to the soil such as loss of organic material as well as soil erosion (Podwojewski et al, 1999). Many contemporary water issues in the Andes, focus on indigenous communities who were forced to move up into the påramo to maintain their ways of living.

Location This study is located in a watershed in the foothills to the south of the volcano Chimborazo near the community Pulingi-San Pablo (See **Figure 1**). The region of Chimborazo is home to one of the highest and unique påramos in the world. The two indigenous communities in the foothills of the tallest peak in Ecuador about 20 km from

Figure 1 shows the location of the two transects that are just south of the volcano Chimborazo. This figure was adapted from Google Earth Pro

the capitol city Riobamba are called Pulingi-San Pablo and Chorrera Mirador. These communities have developed and cultivated the pȧramo land into pastures and for cultivation to make a living. These land use alter plant communities and disturb the soil that change the way the environment absorbs and allows water to flow down into the valley.

With the drastic changes in plant communities from overgrazing, soil cover, and water pathways, it is expected that the water reserves in the Ecuadorian pȧramos will decline in the near future (Poulenard, 1999). The amount of degradation that occurs in the pȧramo, depends on the type of animals grazing in the pastures. It has been shown that the areas most affected are pastured by cows and sheep (Hofstede, 1995).

Because of the impacts of land use on the flora, fauna, soils, and the hydrologic cycle, many indicatives called Compensation for Ecological Services (CES) such as Socio Pȧramo have been started to meet the needs of the local communities and protect the delicate pȧramo ecosystems to maintain their effectiveness as a hydrological reservoir (Farley 2011). The CES indicatives are controversial because it is debatable how effective these programs are at achieving their goals of conserving ecosystems and supporting the local indigenous communities. The communities of Pulingi-San Pablo and Chorrera Mirador are a part of the initiative Socio pȧramo in an attempt to develop a balance between ecotourism of the reserve and their original agricultural practice, to protect the ecosystem and meet their basic needs. SocioPȧramo is an extension of a government funded program called SocioBosque which looks to decrease poverty in rural areas and maintain ecosystems with endemic and native plants (Farley, 2011). One effort with CES in these communities is the use and promotion of alpaca herding to help revitalize the paramo soils and plant communities (Romo, 2014). The community is permitted to graze their alpacas at higher altitudes than their sheep and cattle. Compared to other herd animals, alpacas cause less damage to the soils and plant communities. They are also very valuable economic resources because their meat and wool are very valuable and their presence in the community provides a tourist attraction for foreigners (White).

The Chimborazo pảramo is unique from other pảramos in Ecuador because it is much dryer and lacks the tall stem rosettes that are very common in other northern pảramos. This dryness impacts soil development.

Objectives This investigation looks to investigate their relationship between the regional hydrology of Chimborazo, the local plant communities, and the soils present in the region. Each of these components influence each other and the way the ecosystem operates and evolves. In different sites at different altitudes quantitative soil properties such as bulk density, moisture content, porosity, and saturation will be compared with the qualitative property of texture as well as the diversity and distribution of plant communities. In this study, the impacts of the alpaca grazing will be studied comparatively with a study site at a higher altitude outside of the grazing area of the alpacas to better understand the impacts that the alpacas have on the ecosystem within the socio pảramo program.

Different factors in each site will impact the outcomes of this investigation. It is hypothesized that although soils at higher altitudes will have larger grains and contain less water because more water will drain down the mountainside, soils in the alpaca pastures will have similar properties such as higher bulk density and lower porosity. These soil properties will create an environment more difficult for plant survival, the plant communities in each site will be less diverse and cover less of the soils.

Methods

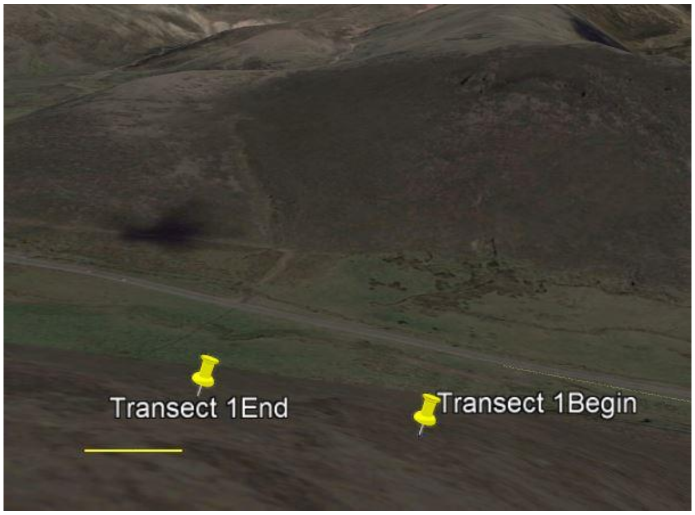


Figure 2A shows the location of Transect 1. This figure was take from Google Earth Pro.

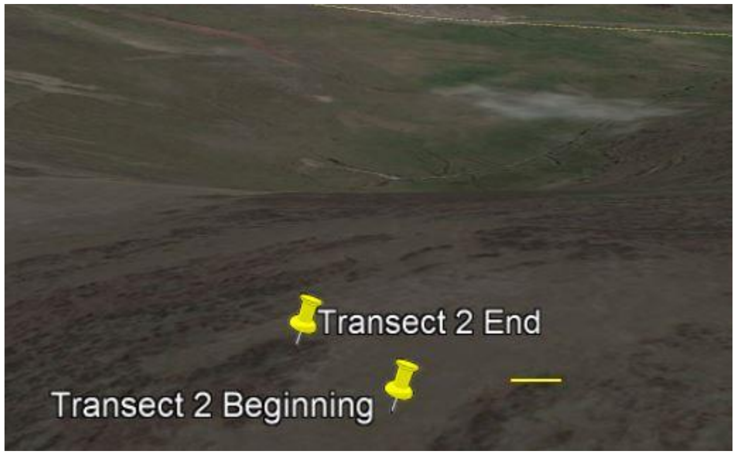


Figure 2B shows the location of Transect 2. This figure was modified from Google Earth Pro.

Materials

- Trowel
- 5 m measuring tape
- string
- hammer
- 11cm x 7.5 cm pipe
- Sample bags
- microwave
- compass

Plant Communities In floristic studies of the pàramo, botanist categorize different taxonomic species into growth forms (Ramsay, 1997). These growth forms are based on their adaptations to survive the harsh weather in the pàramos. Each growth form contains a wide variety of genus and families that have adapted similar forms. These growth forms create different communities throughout the pàramo depending on other environmental factors.

Figure 3 shows the format of the 2 Transect. Each Transect is 30 m long and after every 2 m there is a 1 m x 1 m quadrat where data was collected.

Two 30 m transects were analyzed to study the community composition in two different areas of the pàramo (See **Figure 2A-B**). One site will be at an altitude where alpacas are permitted for grazing, and another at an altitude where alpacas cannot graze. 1m x1m quadrats were studied every third meter along each transect. The individuals in each quadrat were counted and photographed to be classified into growth forms. The growth forms used are based off the ten forms used in Ramsay 1997 and are displayed in **Figure 4** (Ramsay, 1997). These growth forms are described in detail within the methods of Ramsay's investigation. Once the individuals are classified into growth forms, percent coverage of each growth form present was estimated in every quadrat. These community compositions can be compared with classifications of community types present in Ecuadorian

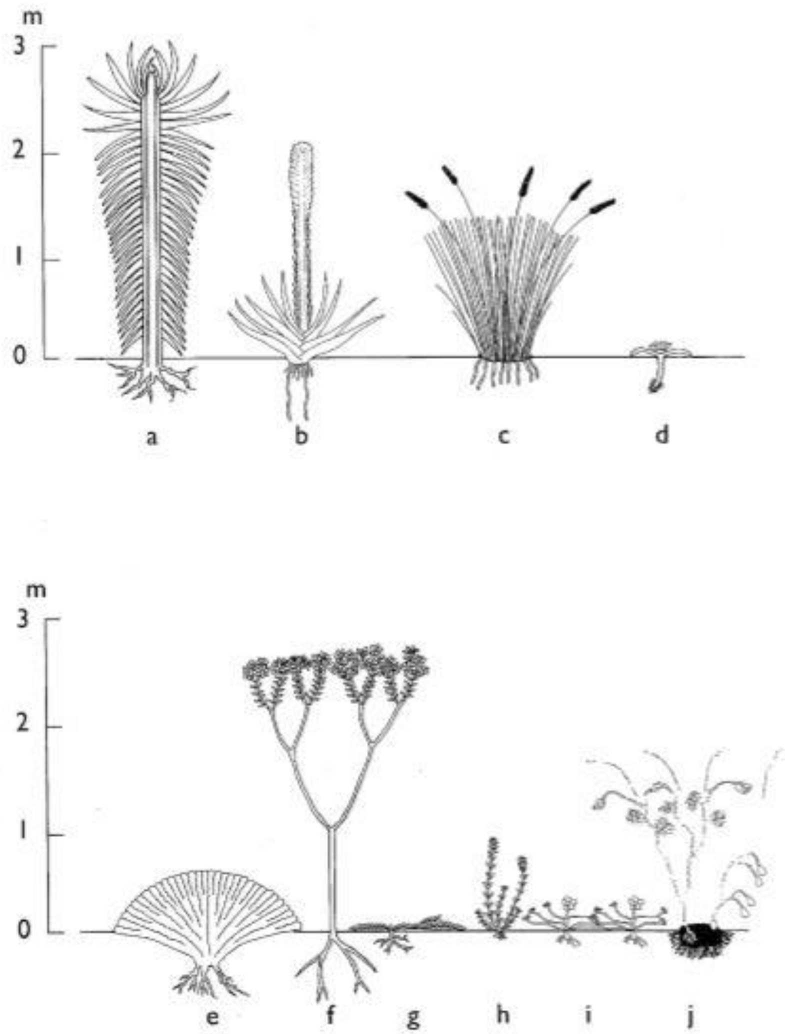


Figure 4 shows the different types of growth forms in the påramos and are pictured as follows: (a) Stem rosette, (b) basal rosette, (c) Tussock, (d) Acaulescent rosette, (e) Cushions, (f) Upright shrub, (g) Prostrate shrub, (h) erect herb, (i) prostrate herb, and (j) trailing herb. Image adapted from Ramsay 1997.

påramos to determine the type of community being analyzed and if the trends in Chimborazo are consistent with previously studied plant communities.

Soil Study Hydraulic conductivity or the soils ability to drain water under saturated conditions, is a very important property of påramo soils. Because of the soil's structure, these high Andean soils are considered to be very important to recharging fresh water reservoirs. Since methods for studying hydraulic conductivity are very tedious and often very dependent on the soil type present (Jabro, 2016), the important factors of hydraulic conductivity were studied to better understand their relationship to the soil's hydraulic conductivity. The main factors that strongly influence hydraulic conductivity are bulk density and grain size distribution or texture (Jabro, 2016).

Undisturbed soil samples are required to study bulk density of the soil. For this investigation of påramo soils, five samples were taken in each quadrat along the plant community transects. In total, 100 undisturbed samples were collected for this investigation. The method in which the samples were extracted was to use a pipe 3.5 cm in diameter and 11 cm long. The pipe was driven into the ground 10 cm with a hammer to collect a specific volume of soil for each sample. Each sample was weighed to measure the total mass of the sample, then microwaved until dry to measure the dry weight of the soil. After the soil is dry five samples from each transect were randomly selected to do the Munsell qualitative texture test. Classifying the samples int textures gives a range of percentages of silt, clay, and sand are present in the soil.

With a total volume (V_t), total weight (W_t), and dry weight (W_s), it is possible to calculate bulk density, porosity, and degree of saturation (See equations 1-5). These calculations indicate important aspects of the soils structure a long each transect. The calculations and textures can be used to better interpret the similarities and differences in the påramo soils.

Analysis of Data The data collected for the three components of this study can be further analyzed and compared together to better understand the relationship between the hydrology of Chimborazo, the regional plant communities, and the physical soil properties.

$$\rho_b = \frac{W_s}{V_t} \quad \textbf{Equation 1}$$

$$n = \frac{\rho_b}{2.65} \quad \textbf{Equation 2}$$

$$w = \frac{W_w}{W_s} \quad \textbf{Equation 3}$$

$$\theta_g = \rho_b \cdot w \quad \textbf{Equation 4}$$

$$S = 100 \cdot \frac{\theta_g}{n} \quad \textbf{Equation 5}$$

Equation 1 describes how to calculate bulk density where ρ_b is bulk density W_s is the weight of the solid material and V_t is the total volume. **Equation 2** describes porosity where n is porosity, ρ_b is bulk density, and 2.65 is a constant. **Equation 3** calculates water content where w is water content, W_w is weight of the water, and W_s is the weight of the solids. **Equation 4** describes volumetric water content which is used to calculate the degree of Saturation where θ_g is volumetric water content, ρ_b is bulk density, and w is water content. **Equation 5** describes degree of saturation where S is saturation, θ_g is volumetric water content, and n is porosity.

For each quadrat percent coverage was estimated in total and for each growth form. These percentages will be entered into a stacked bar graph and compare the results for each quadrat to the growth communities in Ramsay, 1997. Once the soil factors are calculated, the y will be plotted on scatter graphs to study relationships between water content and porosity, and bulk density and water content to study the relationships of these variables. The soil textures and composition will be labeled and defined on a three-variable triangle graph to compare the soil textures in each of the sites. Oneway Anova statistical analysis will be assessed using Vassarstats to study the difference in these variables between the two sites.

Ethics

In order for this study to be conducted successfully, it had to have been conducted in a way that minimized its impacts on the ecosystem as well as the local community. This investigation was completed with the utmost respect to the fragile pàramo ecosystem and the people of Pulingi-San Pablo and Chorrera Mirador. The methods were designed to minimize the impact on the soils and the plant communities in each study area. When extracting soil samples, the method was designed to disturb only the edges of surrounding soil just enough to collect a sample. When collection the samples efforts were made to minimize the disturbance of nearby plant communities. When studying plant communities, to avoid disturbing the composition of the communities, each sample was carefully photographed rather than damaging the plants for physical samples.

This investigation was also conducted in a way to respect the land and people of the community in the province of Chimborazo. The community received a copy of this investigation for their personal records. If they ever need to reference the work in this investigation it will be easily accessible for them to view and share with other scientific investigations as they see fit. The community also received a synopsis of the study in Spanish, to make the investigation more accessible to community members. This synopsis was designed to briefly explain the work in the investigation and explain its significance to better understand the two most important resources in the area, the soil and the fresh water.

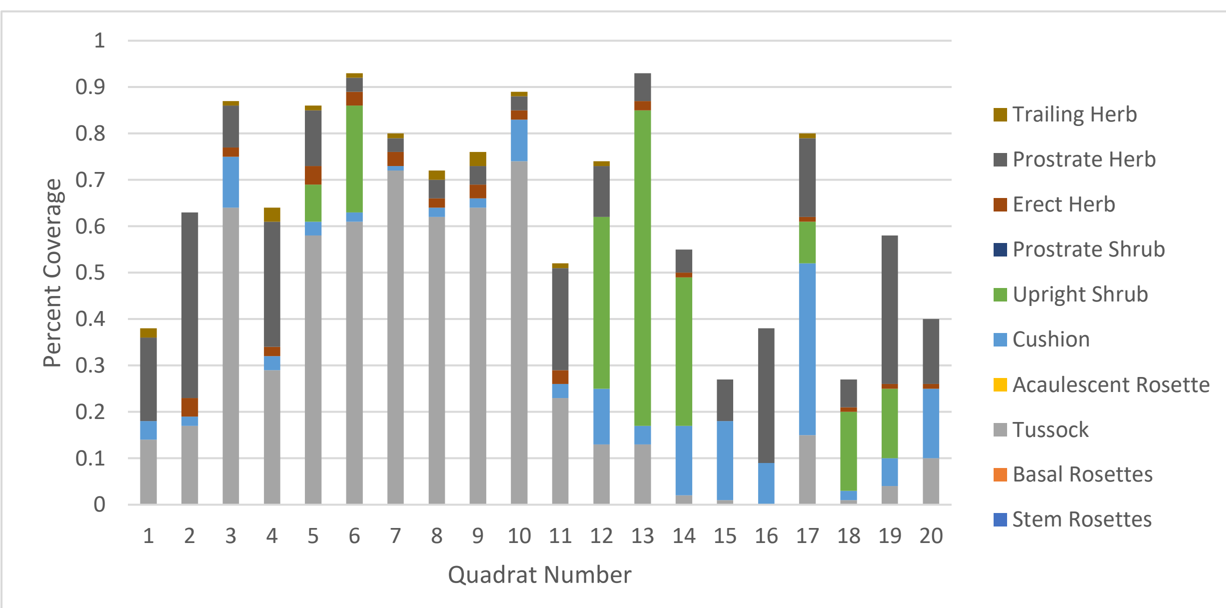


Figure 5 shows the percent coverage data for each growth form in each quadrat. Quadrats 1-10 are along Transect 1 and 11-20 are in Transect 2.

Results

	Bulk Density	Porosity	Water Content	Soil Water Filled Space
Transect 1	0.92	0.65	0.20	28.10
Transect 2	1.16	0.56	0.10	19.84
Total Average	**1.04**	**0.61**	**0.15**	**23.97**

Table 1 shows the average data calculated for bulk density, porosity, water content and soil water filled space. Bulk density is reported in g/cm3. Porosity and water content do not have units and soil water filled space is a percentage.

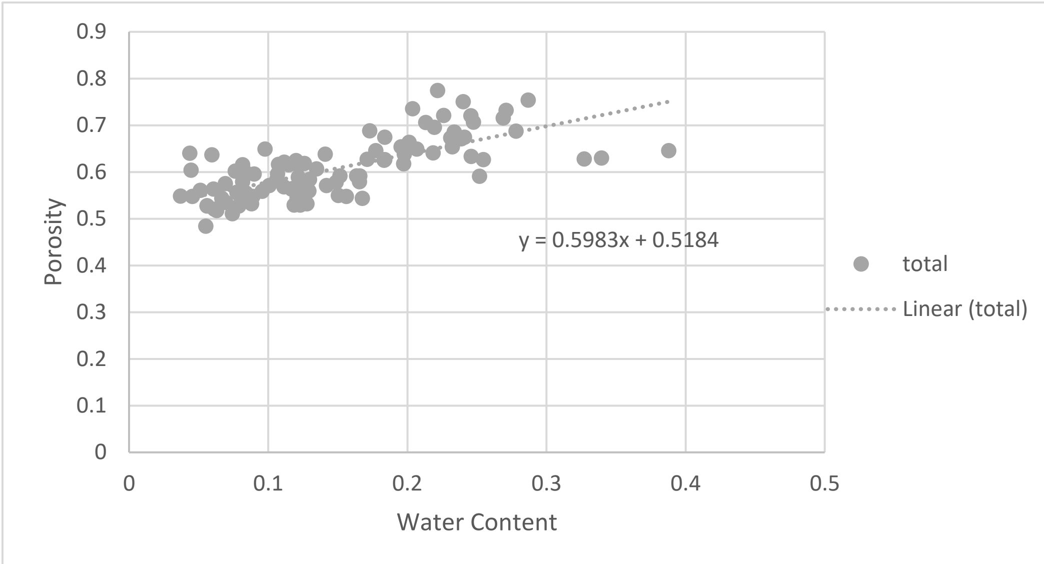
Plant Communities

The total percent coverage of the ten growth forms was calculated between the two transects as 64.6%. In Transect 1 where the alpacas were pastured, on average 74.8% of each quadrat was covered by the ten vascular growth forms while only 54.4% was covered in Transect 2. Of the ten growth forms, only six were present in this study. Prostrate shrubs, Stem Rosettes, Basal Rosettes, and Acaulescent Rosettes were not present in any of the quadrats being studied. **Figure 5** shows the distribution of different growth forms within each quadrat. On average, the most prominent growth form is the tussock form recording 29.9% coverage in all of the quadrats. But between the two transects, Transect 1 on average was 51.5% covered by tussocks while Transect 2 was on average, only covered 8.2%. The difference in the coverage of the tussock growth indicates a great difference in the type of plant community found in each sight. The other growth forms that are most common in both of the study areas are prostrate herbs, cushions, and upright shrubs. As indicated by the coverage of the tussocks, the two transects contain very different community compositions (See **Figure 5**). Although the quadrats along the second transect are much more barren and lack the coverage of Transect 1, they contain more diverse communities. The communities in Transect 2, are more balanced than those in the first transect which is overwhelmingly dominant.

Soil Properties

For each of the soils samples in each transect, bulk density, porosity, water content and Soil water filled space were calculated to further analyze the physical properties of the soil. The averages for each transect and in total are recorded in **Table 1.** Transect 1 recorded a bulk density of .92g/cm3 compared to 1.16g/cm3 in Transect 2. The average porosity for the first transect was calculated to be .65 and .56 for Transect 2. The average water content in Transect 1 was calculated to be .20 and in second transect only .10. The soil water filled space or saturation was calculated to be 28.10% for the first transect and 19.84% for the second transect. The more porous soils of the alpaca pasture absorbed more water than the soils along the transect outside the alpaca pasture.

Water content was directly compared with porosity plotting the data gathered in a scatter plot (See **Figure 6A**). This data suggests a linear relationship between water content and porosity in the physical composition of the páramo soils with a slope of .5983 indicating a direct relationship



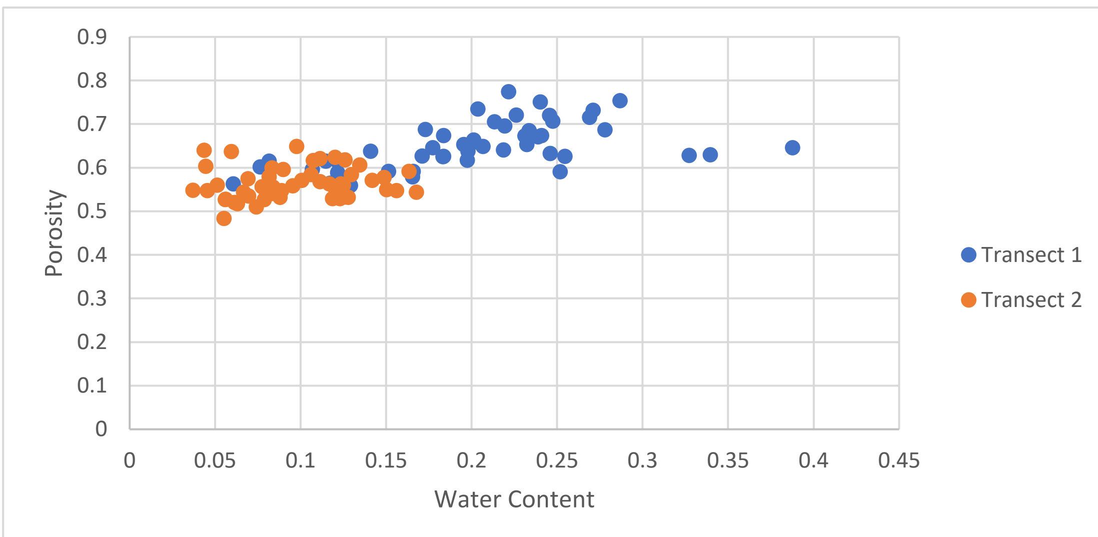
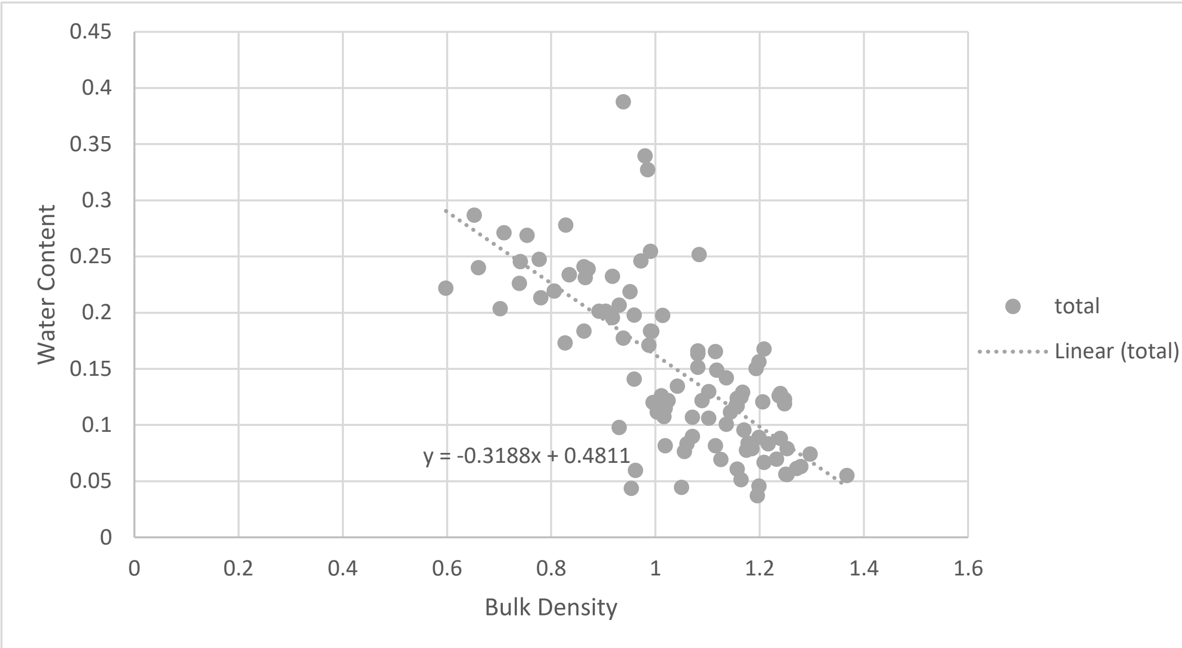


Figure 6A shows water content being compared to the porosity of each soil sample in the data set. **Figure 6B** shows the data plotted based on water content and porosity, but the samples of Transect 1 are labeled in blue and Transect 2 are in orange.

between these two variables. The soils with higher water contents in Transect 1 displayed higher porosities, while soils with lower water content displayed lower porosity like those in Transect 2 (See **Figure 6B**).

In the same way, bulk density was also compared to the water content for each sample on a scatter plot (**Figure 7A**). The Bulk density is directly related to the water content with lower bulk densities having higher water contents. This linear relationship has a slope of -.3188. This split is very clear between Transect 1 and Transect 2 because on average, Transect 1 has lower bulk densities than Transect 2 and has a higher average water content (See **Figure 7B**).



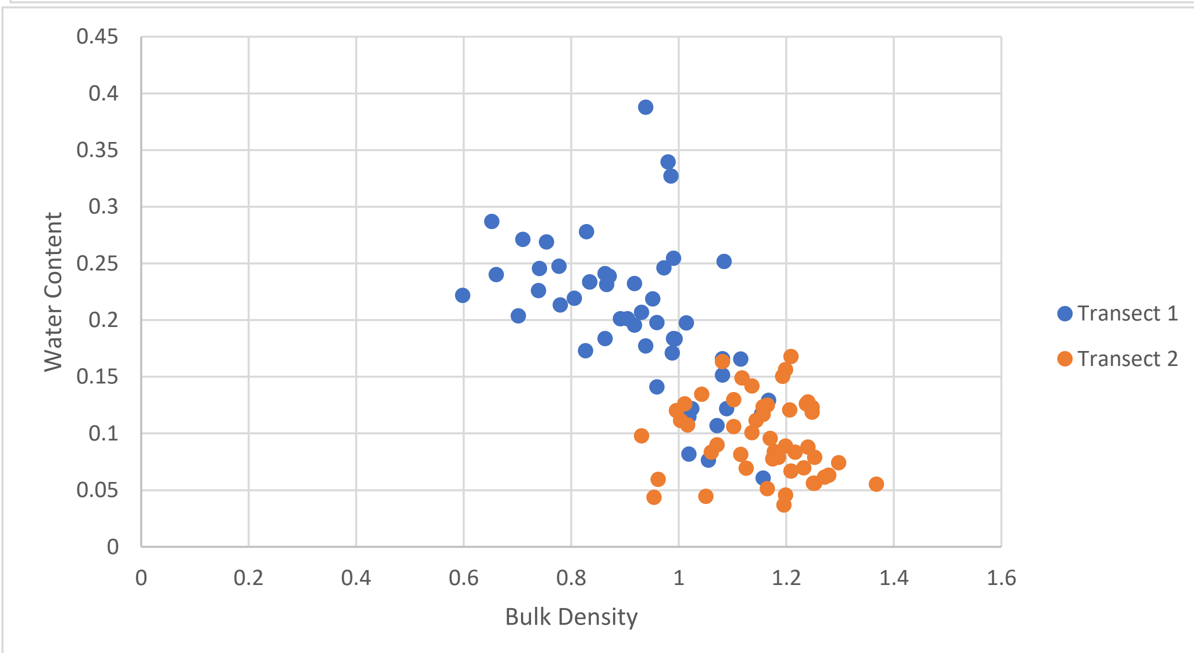


Figure 7A shows the correlation between bulk density and water content for the soil data collected. **Figure 7B** shows this correlation with Transect 1 in Blue and Transect 2 in orange.

Using Munsell's texture guide the texture for each site was qualitatively analyzed to study the distribution of grain size in each site in relation to the other quantitative physical properties (See **Figure 8**). The results indicate very low quantities of clay. In all the samples studied, there was less than 25% clay in both of the areas. The key difference between the soil of Transect 1 and Transect 2, is the ratio of silt to sand in the composition of the soil. The soils in Transect 1 are loams and silty loams. Loams can

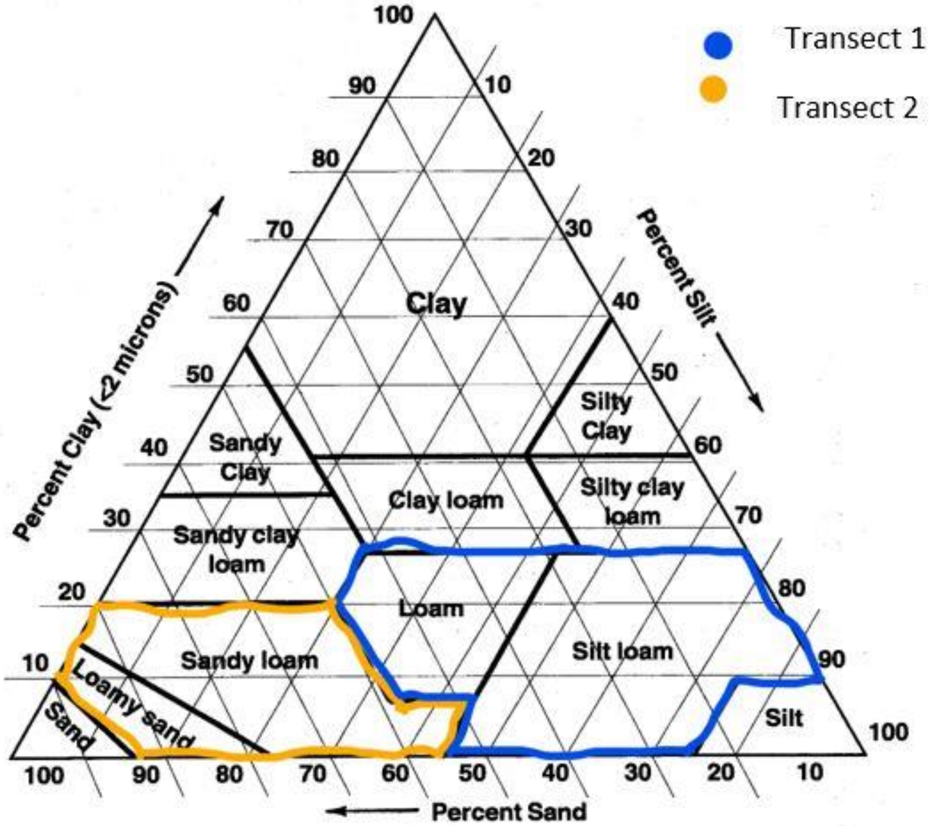


Figure 8 shows the distribution of soil textures found in each transect. This chart indicates the percent composition of each soil texture. Transect 1 is in blue and transect 2 is in orange.

contain 30%- 55% silt and 55%-80% sand. Silty loams contain 55% -90% silt and 10%-55% sand. The ratio of silt sand in Transect 2 is much different than the ratio in Transect 1 because Transect 2 is composed of loamy sands and sandy loams. Loamy sands contain anywhere between 0%-15% silt and 78%-95% sand. Sandy loams contain between 0%-55% silt and 55%-90% sand.

Difference Between the Sites Using Vassarstats a One-way Anova test was conducted to quantify the difference between each site for each of the soil properties studied. The P value in the One-way Anova test indicates the significant difference. The F test is also used to study the variation of the sample means.

The Anova Summary studying the variable of bulk density between the two transects indicates a significant difference with a P value of <.0001 (See **Table 2**). With this low of a P value, the Anova test indicates very clearly that there is a significant difference and rejects the null hypothesis of the test that states there is no difference between the two sites. For the F test, the value of 94.54 was recorded indicating the high difference in means of the bulk density in the two transects.

Anova Summary Bulk Density					
	SS	df	MS	F	P
Treatment	1.369957	1	1.369957	94.54	<.0001
Error	1.420118	98	0.014491		

Anova Summary Water Content					
	SS	df	MS	F	P
Treatment	0.285815	1	0.285815	101.82	<.0001
Error	0.275089	98	0.002807		

Anova Summary Porosity					
	SS	df	MS	F	P
Treatment	0.195081	1	0.195081	94.54	<.0001
Error	0.202224	98	0.002064		

Anova Summary Saturation					
	SS	df	MS	F	P
Treatment	1707.939	1	1707.939	25.38	<.0001
Error	6594.691	98	67.293		

Table 2 shows the Anova summary for bulk density reporting sum of squares, degrees of freedom, mean squares, the F value, and P value. **Table 3** reports the Anova summary comparing water content between the 2 transects. **Table 4** reports the Anova summary comparing porosity between the two transects. **Table 5** shows the Anova summary for Saturation between the two transects.

The P value for the summary of Anova data for water content is also <.0001 demonstrating a significant difference in water content for each site (See **Table 3**). The null hypothesis of there is no difference in water content on each transect is rejected. For the F test, the F value is reported as 101.82. This F value indicates a high variation I n the means of water content along the transects.

The Anova summary for porosity shows a P value of <.0001 suggesting that this data set rejects the null hypothesis that there is no difference in porosity between Transect 1 and Transect 2 (**Table 4**). With this significant difference, the F test was also reported to be 94.54. Since porosity was calculated using bulk density it is sensible that the variation in means for each transect would generate the same f value.

In the Anova summary for the saturation of the soil for each transect, the P value was calculated as <.0001 which suggests a significant difference in the data (**Table 5**). This data rejects the null hypothesis that the two transects had no difference in saturation. The F value was recorded as 25.38. This indicates that there is variability in the means, but not nearly as much as the other variables tested.

Discussion

It is evident from previous studies (Hofstede, 1995; Podwojewski et al, 1999), land use impacts the composition of local plant communities and soil properties in the pȧramo. Studies have also shown that plant communities or more specifically an engineer species within a community, impacts the soils present (Bandano et al, 2006). Soil types also have an impact on the type of plant communities based on their physical and chemical properties. In the pȧramo, these factors also impact the regional hydrology and fresh water resources in the region.

Plant Communities of Chimborazo

The key characteristics of the plant communities along Transect 1 are the dominances of tussocks, the high overall coverage within each quadrat, and the lack of the stem rosettes, basal rosettes, acaulescent rosettes, and prostrate shrubs. The communities represented in these quadrats contain a low evenness in growth forms because of the dominance of the tussocks.

The communities along Transect 2 were much different from those in Transect 1 because there was a significantly lower average percent coverage (54.4%), and there was better evenness in the growth forms present in the community. The most common growth forms present in these communities were upright shrubs (17.8%), prostrate herbs (15.1%), cushions (12%), and tussocks (8.2%). These communities were similar to those in Transect 1 because the growth forms that were not present were the same.

Ramsay (1997) developed communities based on the coverage of different growth forms. In total Ramsay found 8 of the 10 growth forms within his study areas in Chimborazo compared to the 6 found within the study area of this investigation. This count is still consistent within Ramsay's study, he only found on average 5.4 growth forms in the different altitudinal ranges that were studied. Across Ecuadorian pȧramos, names for different communities present, were made to classify these different communities. The dominant communities that Ramsay found in the Chimborazo were Tussock pȧramo communities and desert cushion communities. Transect 1 is similar to the Tussock pȧramo communities because of the low diversity in growth forms, but high coverage of tussock grasses. The cushion desert is characterized by lower percent coverages and much more diverse composition of growth forms especially cushion rosettes, and erect herbs (Ramsay, 1997). Transect 2 is similar to this community but contains many upright shrubs and prostrate herbs. Ramsay concluded that percent coverage of vascular plants decreases with altitude while the richness and diversity of growth forms and species increases with altitude. This investigation is in line with these conclusions because the richness of growth forms is much higher on in Transect 2 which is at a higher altitude than Transect 1.

There is evidence that cushion plants are drivers in improving community diversity and richness. According to studies (Bandano, 2006) cushion plants do not cause any noticeable changes in the soil chemistry but increase stability of species richness in communities. Cushion plants are considered engineer species because of their influences on abiotic factors. It has been shown that these plants reduce wind speeds and maintain constant substrate temperatures (Bandano, 2006). Reducing wind speed creates a less challenging in environment above the surface as well as in the soil because slower winds cause less erosion. The constant substrate temperatures create more comfortable environments for plants to develop their roots in an environment with reduced risks for freezing. Cushions are also capable of retaining 50% - 70% more water (Bandano, 2006). Although the soils directly beneath the cushions contain more water than the surrounding soil, this improves the diversity of the growth forms in the plant communities containing higher percent coverage of cushion plants.

Land-use especially the conversion to pastures impacts the types of plant communities present. Many methods of land conversion to pastures includes burning native vegetation. This method introduces more organic material to the soil but decreases the diversity of plant communities (Buytaert et al 2006). Within Transect 1, only alpacas were permitted for grazing. Compared to cattle, the impacts of alpaca grazing are minimal. The foraging habits of alpacas differ greatly than those of cattle and sheep. Alpacas eat a wider range of food than the other pastured animals, this allows for plant communities to better maintain their original structure. While pastures with more selective feeders become unbalanced because of the selection against fewer plant species. Although there is less diversity in growth forms in the transect in the pastured area. This zone appears to be closer match the community descriptions within the Chimborazo pȧramo than those along Transect 2. This similarity indicates that although sheep and cattle have a large impact on plant communities, the alpacas have little to no effect on the plant communities. This suggests that they are a sustainable means of developing the land in the pȧramo.

Soil Properties The distinct differences in soil properties between the two sites in this investigation indicates a correlation between soil types and plant communities present on the soil types. The soils of Transect 1 had higher water contents and porosities and lower bulk densities than the soils in Transect 2. Although the growth forms in Transect 1 were not very diverse, the high coverage of tussocks added a significant amount of organic matter to the soil. Organic matter is very important for storing water (Gupta et al, 1979). In other pȧramo soil investigations, it is found that there are already high quantities of organic matter in volcanic ash soils. In dryer pȧramos, the organic matter in the volcanic ash and from the tussocks are the key factors which hold water. In comparison to pȧramos in southern Ecuador that also contain high concentration of clay because the age of the soil is much older and has had more time to weather. These soils contain concentrations of allophane which is a type of mineral that its chemical composition bonds and is hydrated with water (Buyteart, 2004).

The bulk densities in Transect 1 are much lower than those in in Transect 2 because of the differences in grain size and composition. Although both transects had very low quantities of clay, the textures of the soil in transect 1 are much smoother because they lack the large grain sizes of the sand. The smaller grain sizes allow for smaller bulk densities, with these smaller bulk densities the higher porosities are calculated. The grain size of the soils is a factor of how much physical weathering has occurred on the soil. The soils at higher altitudes are exposed to conditions less prone to physical weather because of the lower temperatures. The grain size and soil textures are not to be considered as products of land use or as being engineered by the plant community but rather because of the difference in climate and temperature on an altitude gradient in the pȧramo. In Transect 2 where the soil texture is more sandy, there is less organic material and nutrients, there is a greater richness in vascular plant growth forms. The higher diversity in growth forms is a result from the abiotic factors of soil quality and harsher climate.

As described in the introduction, the physical structure of the pȧramo soils is very unique to the ecosystem because of their low bulk densities and hydraulic conductivity. Historically the effects of overgrazing on the pȧramo soils causes great risks to soil quality because of the damage it causes to the soil's physical structure (Poulinard, 2001). The soils in the alpaca pasture demonstrated lower bulk densities than those in the transect in the undisturbed pȧramo. With little studies conducted on the impact of alpaca grazing, this information highly contrasts previous studies conducted on pasture land in the pȧramo. Over grazing decreases the carbon content of the soil because much of the land is stripped of its native vegetation (Podwojewski, 2011). The vulnerability to erosion is also increased because of the material that was trampled and loosened soil on steep Andean slopes (Podwojewski, 2011).

Error Sources of error within this investigation can be found in the assumptions of extracting perfectly undisturbed soil samples. It is impossible to perfectly extract a soil sample without at least disturbing the edges where the pipe is wedged into the soil. Collecting a high quantity of samples is a way to ensure that accidental compression and loosening of soil balances out over the sample taking process.

Another source of error is in the drying process of the samples. When these samples were dried they needed to be transferred into microwavable containers. In this process, it possible small traces of soil were not removed for the bags and caused inaccuracies in the dry weight measurement of each sample.

Conclusion

Along Transect 1 which is in the Alpaca pasture, the growth form of tussock dominates these plant communities. These tussock communities are very common in the pȧramos of Chimborazo (Ramsay, 1997). In Transect 2 where there was no grazing, there was significantly lower percent coverage, but the diversity of growth forms is much higher. The differences in plant communities do not fit the characteristics of plant communities that are overgrazed. Overgrazed areas have low overall percent coverage. Since Transect 2 has a low percent coverage than Transect 1, it is evident that the alpacas do not have a large impact on the coverage of growth forms within the pastures. Many studies indicate the impact of the temperature change on the altitudinal gradient causes pȧramo plant communities to be distributed in this way (Ramsay, 1999; Vasconez, 2006). The plant communities are more impacted by the abiotic factors such as temperature and soil texture rather than the biotic pressure of grazing by the alpaca herds.

The soils found in Transect 1 contained lower bulk densities than those of Transect 2. This information indicates information of the biota's impact on the physical composition of the soils. The soils with lower bulk densities had finer textures being composed of a higher percentage of silt rather than sand. The siltier soils of Transect 1 had higher percent coverages but lower diversity of growth forms within each quadrat. The sandier soils in Transect 2 had a lower overall percent coverage, but no growth form particularly dominated the quadrats. These quadrats in Transect 2, had a higher coverage of cushion plants. Cushion plants are considered to be "engineers," meaning that they are capable of altering abiotic factors to create more favorable conditions for themselves and other species (Bandano, 2006). The more challenging abiotic conditions of these higher altitude native pȧramos ironically creates more opportunity for different growth forms to be successful.

The water content, porosity, and degree of saturation were recorded to be higher on Transect 1 than Transect 2. Because of the soils lower bulk density and higher concentration of organic matter from the tussocks, the soils in the quadrats along the first transect have a higher capacity to absorb water than the sandier soils with less plant coverage. Since the soils in Transect 1 have a higher capacity to absorb water than the soils on Transect 2, little to no effects from the grazing are evident in the alpaca pasture. The alpacas cause very little environmental damage to the pȧramo ecosystem compared to other land uses. In future studies, the impacts of alpacas should be directly compared to the impacts of sheep and cattle. A study that does a direct comparison of the impacts of other grazing compared to alpaca grazing will improve the understanding of sustainable land-use in the Andean pȧramos.

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